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Aki

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(54) **POSITION MEASUREMENT APPARATUS AND POSITION MEASURING METHOD**

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G01B 11/02 (2006.01)

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CPC ***G01B 11/02*** (2013.01)

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CPC G01B 11/02; H04N 7/18; H04N 7/00
USPC 348/135, 142, 148, 149; 340/146; 382/46, 61, 104, 284, 294, 106, 3.06, 382/103, 145, 299; 83/13; 356/3.06; 702/127; 353/70
See application file for complete search history.

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(57) **ABSTRACT**

In a position measurement apparatus and a positioning measuring method, an image capturing element having an imaging region of a dimension smaller than that of a workpiece is moved relatively over a surface of the workpiece while an image on the surface of the workpiece is captured. In addition, a pattern on the surface of the workpiece is extracted from an image (I(t)) inside the imaging region, and a displacement amount of the pattern occurring in the image (I(t+1)) inside the imaging region is detected. A position on the surface of the workpiece is measured based on the detected displacement amount and the dimension.

16 Claims, 13 Drawing Sheets

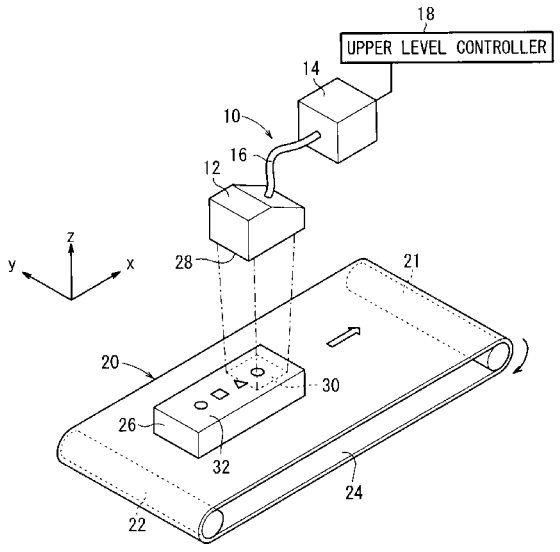

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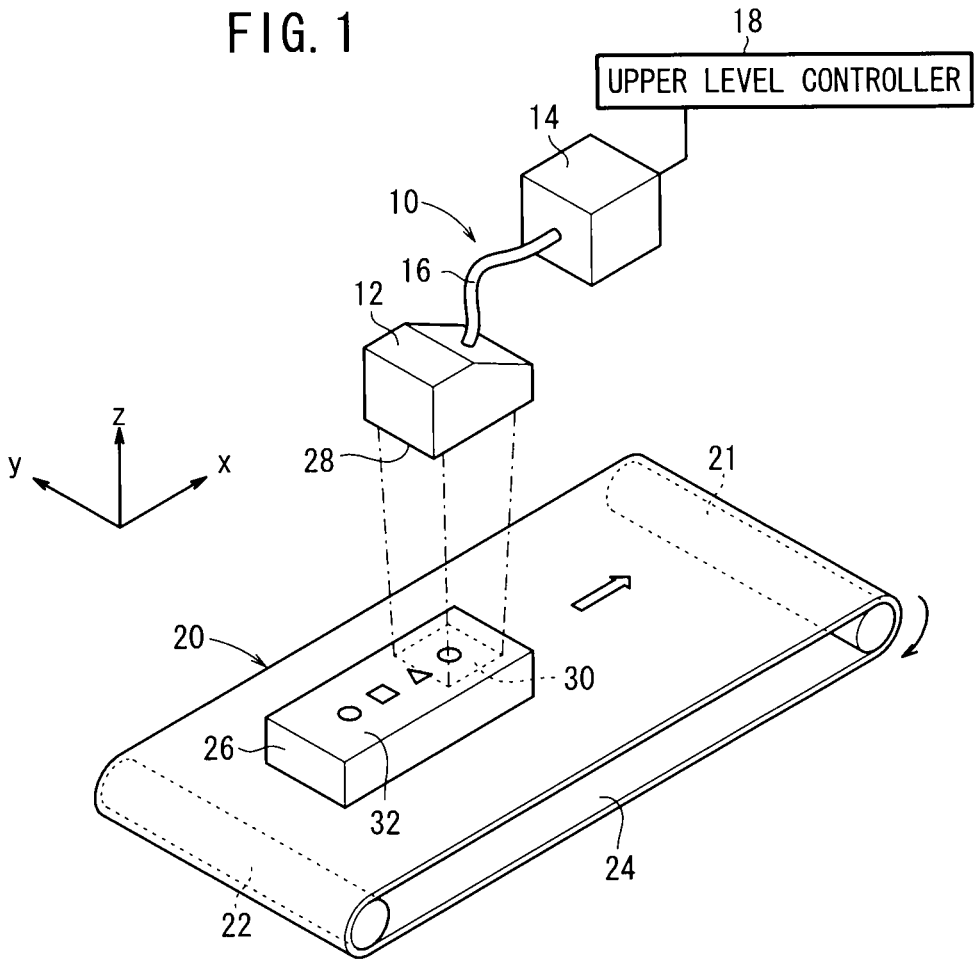
FIG. 1



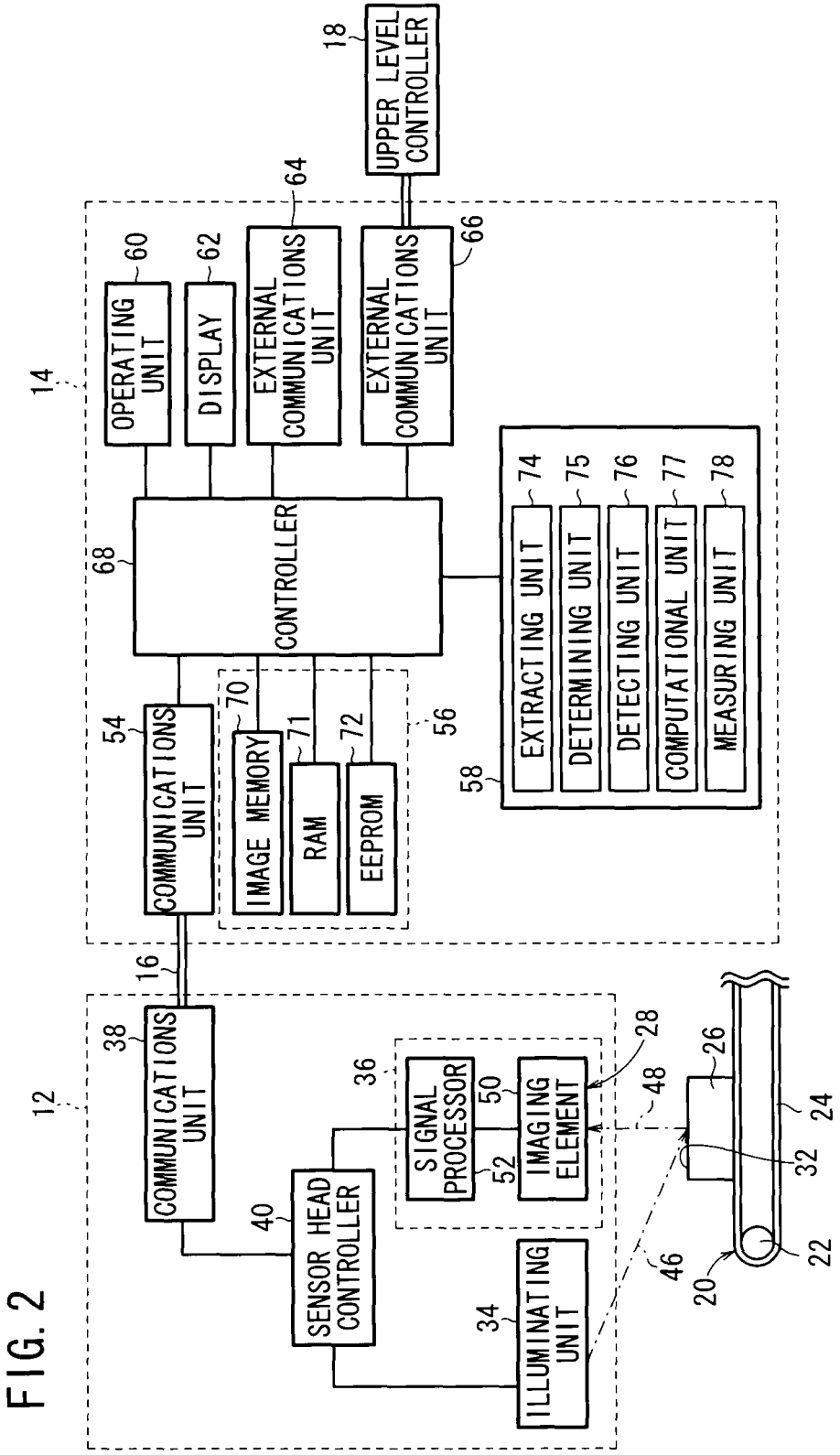

UPPER LEVEL CONTROLLER
18
64
66
OPERATING UNIT
60
DISPLAY
62
EXTERNAL COMMUNICATIONS UNIT
EXTERNAL COMMUNICATIONS UNIT
14
68
CONTROLLER
74
75
76
77
78
EXTRACTING UNIT
DETERMINING UNIT
DETECTING UNIT
COMPUTATIONAL UNIT
MEASURING UNIT
58
54
COMMUNICATIONS UNIT
70
IMAGE MEMORY
71
RAM
72
EEPROM
56
16
12
38
COMMUNICATIONS UNIT
36
SIGNAL PROCESSOR
50
52
IMAGING ELEMENT
28
48
26
24
32
40
SENSOR HEAD CONTROLLER
34
ILLUMINATING UNIT
46
20
22

FIG. 2

FIG. 3A

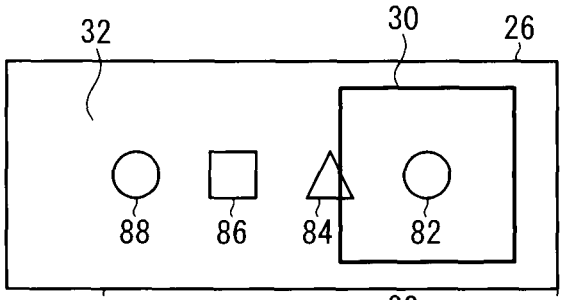


FIG. 3B

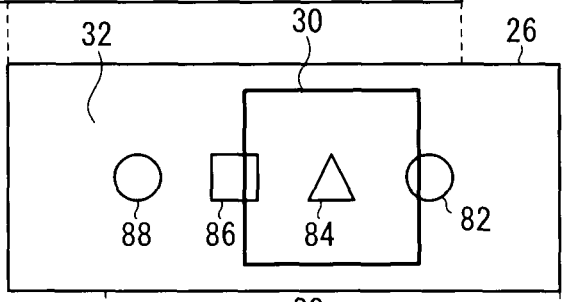


FIG. 3C

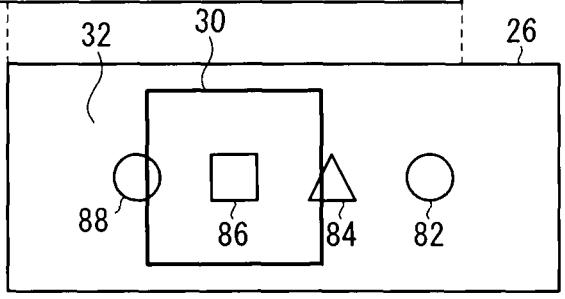


FIG. 4

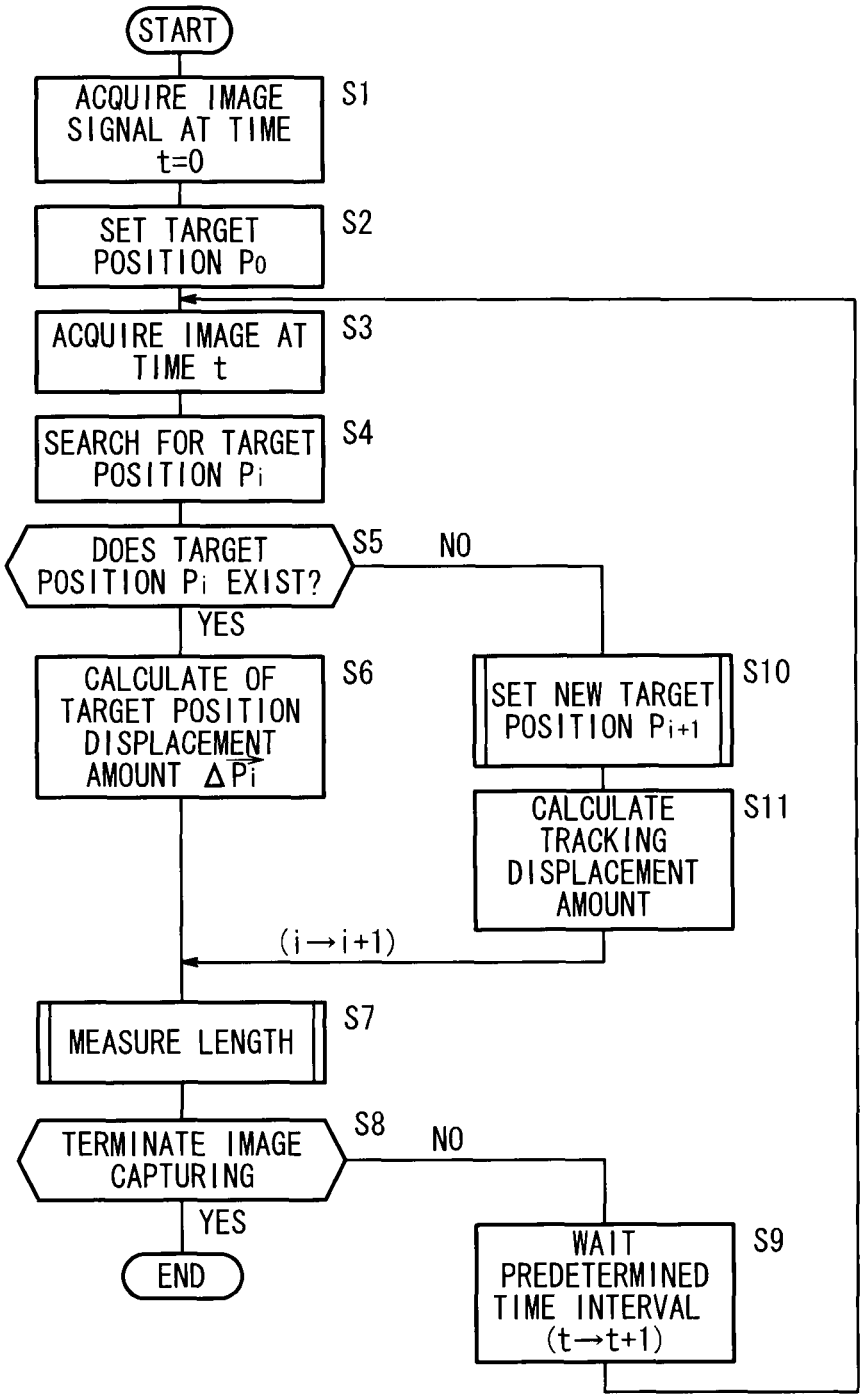

START
ACQUIRE IMAGE SIGNAL AT TIME t=0
S1
SET TARGET POSITION Po
S2
ACQUIRE IMAGE AT TIME t
S3
SEARCH FOR TARGET POSITION Pi
S4
DOES TARGET POSITION Pi EXIST?
S5
NO
YES
CALCULATE OF TARGET POSITION DISPLACEMENT AMOUNT ΔPi
S6
SET NEW TARGET POSITION Pi+1
S10
CALCULATE TRACKING DISPLACEMENT AMOUNT
S11
(i→i+1)
MEASURE LENGTH
S7
TERMINATE IMAGE CAPTURING
S8
NO
YES
END
WAIT PREDETERMINED TIME INTERVAL (t→t+1)
S9

FIG. 5A

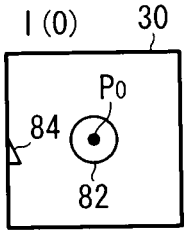


FIG. 5B

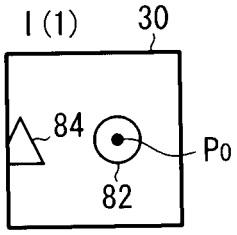


FIG. 6A

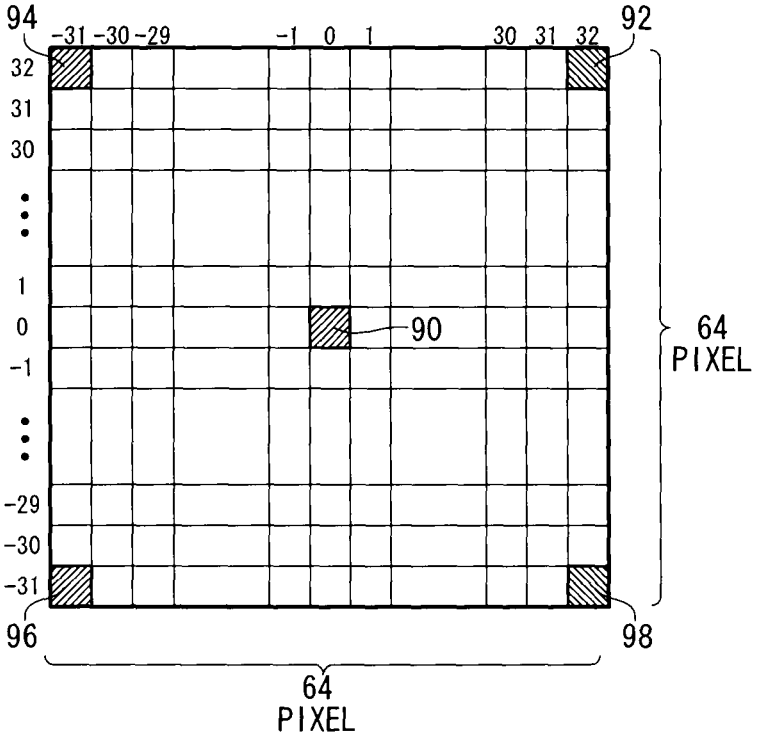

94
92
-31 -30 -29
-1 0 1
30 31 32
32
31
30
1
0
-1
-29
-30
-31
90
64
PIXEL
96
98
64
PIXEL

FIG. 6B

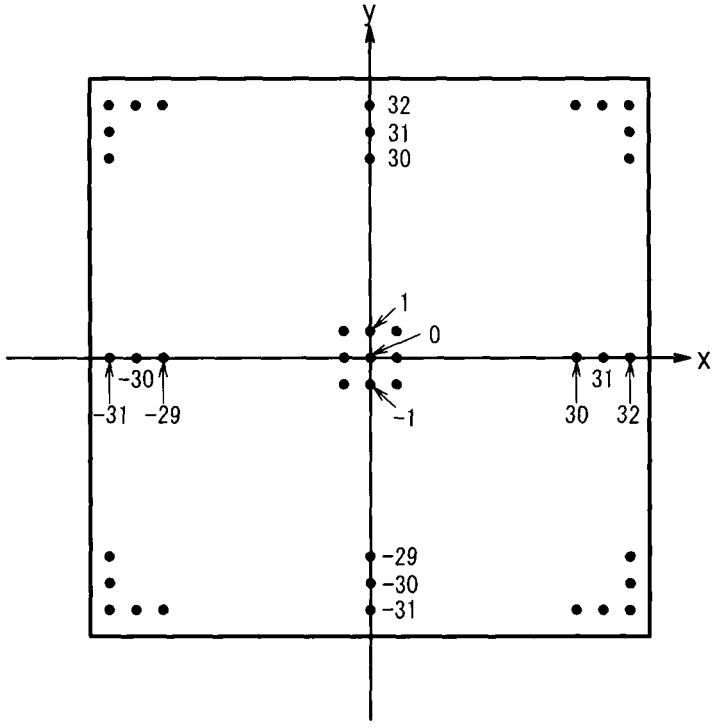

y
x
32
31
30
1
0
-30
-31 -29
-1
31
30 32
-29
-30
-31

FIG. 7A

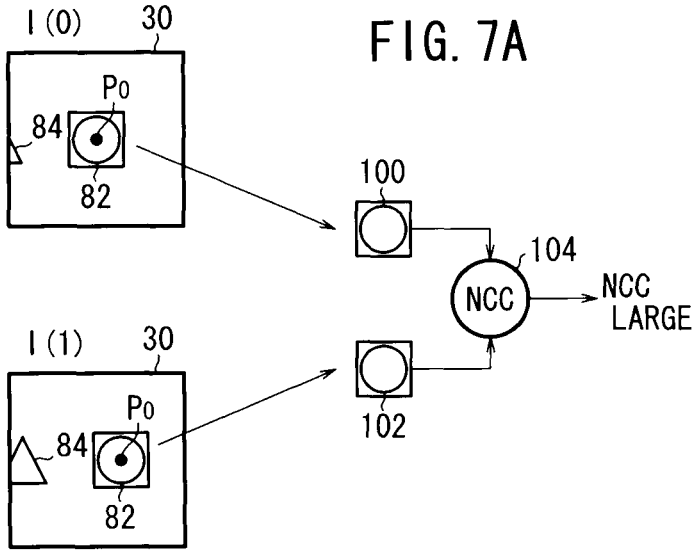

I (0)
30
P0
84
82
100
104
NCC
NCC
LARGE
I (1)
30
P0
84
82
102

FIG. 7B

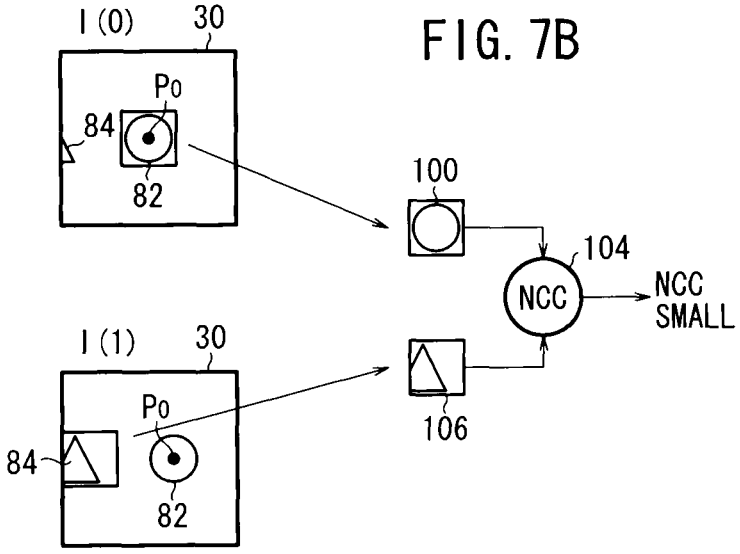

I (0)
30
P0
84
82
100
104
NCC
NCC
SMALL
I (1)
30
P0
84
82
106

FIG. 8A

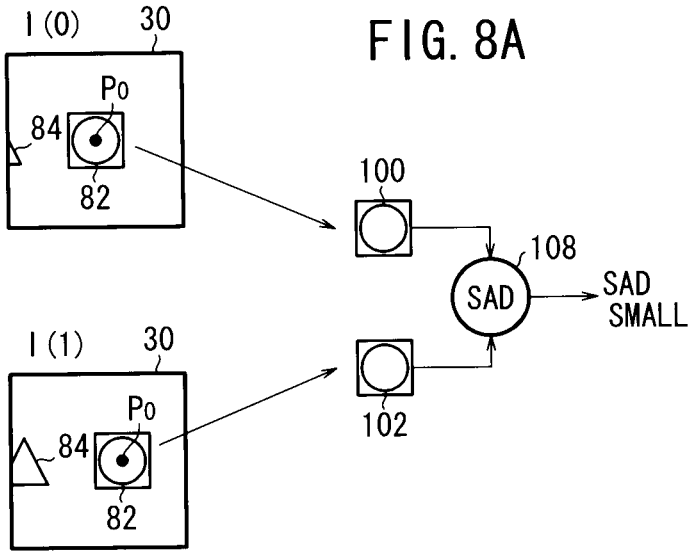

I (0)
30
P0
84
82
100
108
SAD
SAD
SMALL
I (1)
30
P0
84
82
102

FIG. 8B

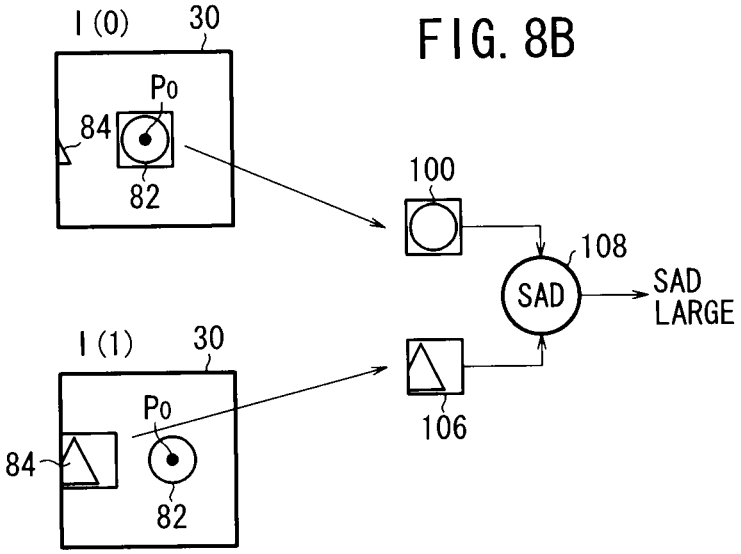

I (0)
30
P0
84
82
100
108
SAD
SAD
LARGE
I (1)
30
P0
84
82
106

FIG. 9

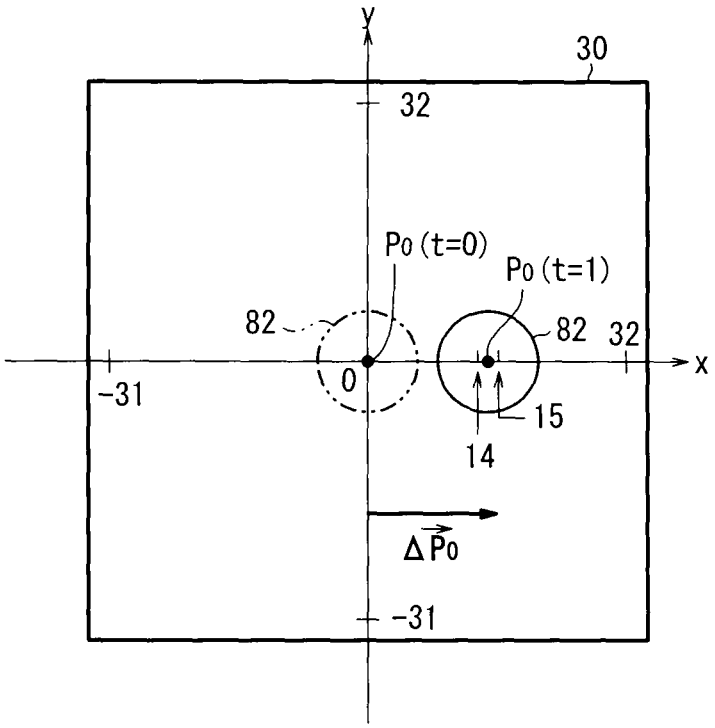


FIG. 10

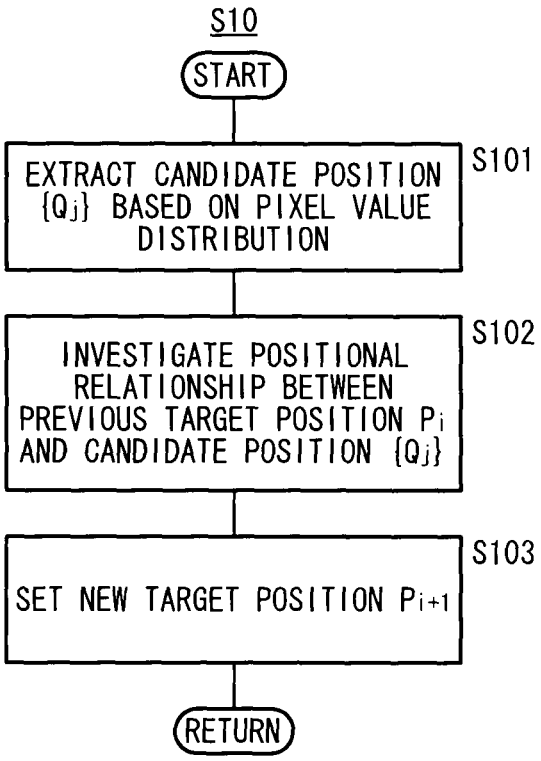

S10
START
EXTRACT CANDIDATE POSITION {Qj} BASED ON PIXEL VALUE DISTRIBUTION
S101
INVESTIGATE POSITIONAL RELATIONSHIP BETWEEN PREVIOUS TARGET POSITION Pi AND CANDIDATE POSITION {Qj}
S102
SET NEW TARGET POSITION Pi+1
S103
RETURN

FIG. 11

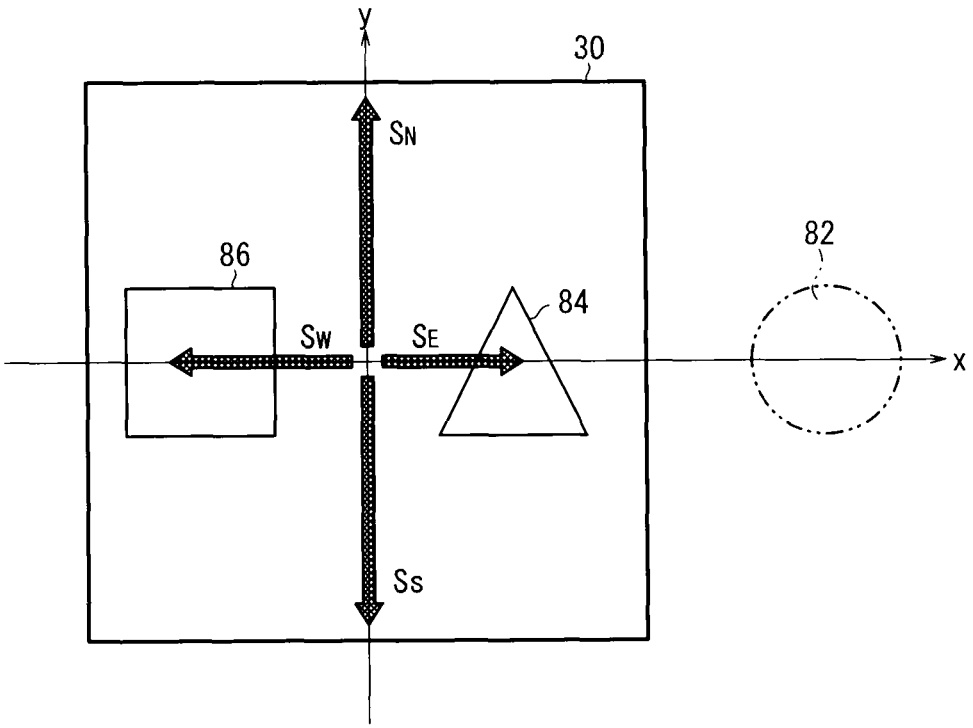


FIG. 12

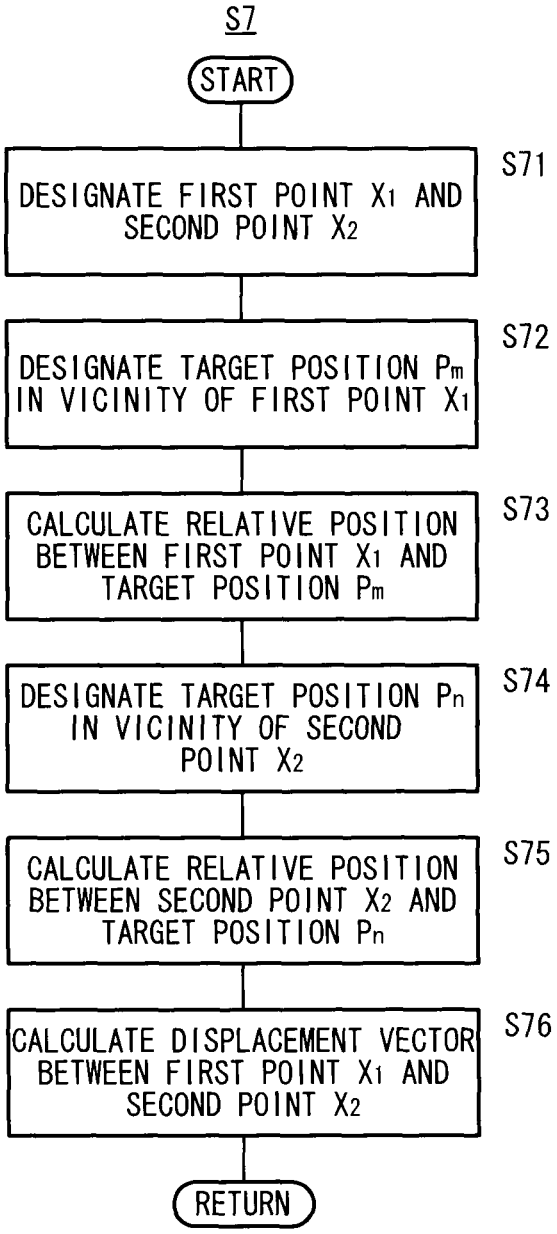
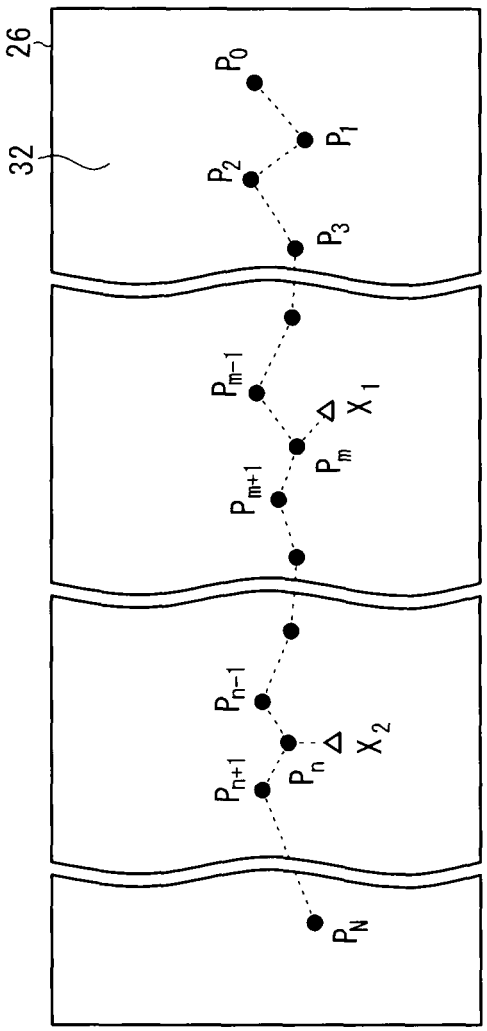

S7
START
DESIGNATE FIRST POINT X1 AND SECOND POINT X2
S71
DESIGNATE TARGET POSITION Pm IN VICINITY OF FIRST POINT X1
S72
CALCULATE RELATIVE POSITION BETWEEN FIRST POINT X1 AND TARGET POSITION Pm
S73
DESIGNATE TARGET POSITION Pn IN VICINITY OF SECOND POINT X2
S74
CALCULATE RELATIVE POSITION BETWEEN SECOND POINT X2 AND TARGET POSITION Pn
S75
CALCULATE DISPLACEMENT VECTOR BETWEEN FIRST POINT X1 AND SECOND POINT X2
S76
RETURN

FIG. 13



POSITION MEASUREMENT APPARATUS AND POSITION MEASURING METHOD

CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2009-160860 filed on Jul. 7, 2009, of which the contents are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a position measurement apparatus and a position measuring method for measuring a position on the surface of a measurement object by capturing an image of the surface of the measurement object.

2. Description of the Related Art

For measuring the length of a measurement object (in the present specification, this is referred to as the total length of the measurement object, the size of a part thereof, or the displacement, etc., of the measurement object), an image capturing position measurement apparatus has been used. Such a position measurement apparatus captures an optical image irradiated from the surface of the measurement object using an image sensor made up of a CCD, CMOS image sensor array or the like, and analyzes the image signal obtained by such image capturing to thereby measure the length of the measurement object.

For example, in Japanese Laid-Open Patent Publication No. 2002-013948 and in Japanese Laid-Open Patent Publication No. 2003-148918, systems are disclosed in which an imaging region with respect to a measurement object is set narrowly, so that displacement of the measurement object can be measured at high resolution and with high accuracy.

However, even when such an image capturing displacement measurement apparatus is used, in the case that the length of a measurement object having a large measurement range is to be measured, because a trade off relationship occurs between the size of the measurement range and spatial resolution, various difficulties in measurement tend to occur. Specifically, when the image capturing magnification ratio is small, although the entire measurement object can be set inside of the imaging region, on the other hand, since the imaging spatial resolution is decreased, sufficient measurement accuracy cannot be obtained.

Further, when the image capturing magnification ratio is made larger, although good measurement accuracy can be obtained because imaging spatial resolution is improved, the entire measurement object cannot be set inside of the imaging region. Stated otherwise, this is because the imaging region and spatial resolution are finite since there is a limit imposed on the capacity of the image sensor and the configuration of the apparatus.

On the other hand, although it can be considered to increase the number of pixels that make up the image sensor and to provide a configuration having a large imaging region, this will make the position measurement apparatus large in scale and drastically increase manufacturing costs thereof.

SUMMARY OF THE INVENTION

A general object of the present invention is to provide a position measurement apparatus and position measuring method in which an increase in size and rise in manufacturing costs of the apparatus are prevented, while also enabling the length of a measurement object to be measured, even in the case that the measurement range of the measurement object is either narrower or wider compared with the imaging region.

The present invention is characterized by a position measurement apparatus, in which an image capturing element having an imaging region of a dimension smaller than that of a measurement object is moved relatively over a surface of the measurement object while an image on the surface of the measurement object is captured to obtain an image inside the imaging region, and a position on the surface of the measurement object is measured using the obtained image inside the imaging region. The position measurement apparatus comprises an extracting unit for extracting a pattern on the surface of the measurement object from the image inside the imaging region at a predetermined point in time, a detector for detecting a displacement amount of the pattern extracted by the extracting unit occurring in the image inside the imaging region at a point in time after the predetermined point in time, and a measurement unit for measuring the position on the surface of the measurement object based on the dimension and the displacement amount detected by the detector.

According to the present invention, because the extracting unit for extracting a pattern on the surface of the measurement object and a detector for detecting a displacement amount of the pattern occurring in the image inside the imaging region are provided, while the image sensor is moved relatively over the surface of the measurement object which is larger than the imaging region of the image sensor, the relative positional relationship between the measurement object and the imaging region is capable of being grasped based on the displacement amount of the pattern both within and outside of the imaging region. Hence, even in the case that the measurement range of the measurement object is either narrower or wider compared with the imaging region, the position on the surface of the measurement object can be measured.

The present invention is further characterized by a position measuring method, in which an image capturing element having an imaging region of a dimension smaller than that of a measurement object is moved relatively over a surface of the measurement object while an image on the surface of the measurement object is captured to obtain an image inside the imaging region, and a position on the surface of the measurement object is measured using the obtained image inside the imaging region. The method comprises the steps of extracting a pattern on the surface of the measurement object from the image inside the imaging region at a predetermined point in time, detecting a displacement amount of the pattern extracted by an extracting unit occurring in the image inside the imaging region at a point in time after the predetermined point in time, and measuring the position on the surface of the measurement object based on the dimension and the displacement amount detected by a detector.

According to the present invention, because steps are provided for extracting a pattern on the surface of the measurement object and detecting the displacement amount occurring in the image inside the imaging region, while the image sensor is moved relatively over the surface of the measurement object which is larger than the imaging region of the image sensor, the relative positional relationship between the measurement object and the imaging region is capable of being grasped based on the displacement amount of the pattern both within and outside of the imaging region, and hence, even in the case that the measurement range of the measurement object is either narrower or wider compared with the imaging region, the position on the surface of the measurement object can be measured.

The above and other objects, features and advantages of the present invention will become more apparent from the following description when taken in conjunction with the accompanying drawings in which preferred embodiments of the present invention are shown by way of illustrative example.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an outline perspective view of a position measurement apparatus according to an embodiment of the present invention;

FIG. **2** is a functional block diagram of the position measurement apparatus according to the embodiment of the present invention;

FIGS. **3**A to **3**C are outline front views showing a positional relationship between a measurement object and an imaging region;

FIG. **4** is a flowchart for implementing a position measuring method according to an embodiment of the present invention;

FIG. **5**A is a schematic view showing an image inside the imaging region at a time t=0;

FIG. **5**B is a schematic view showing an image inside the imaging region at a time t=1;

FIG. **6**A is an explanatory diagram of an image signal representing an image inside the imaging region;

FIG. **6**B is an explanatory diagram representing corresponding positions of each of pixels inside the imaging region;

FIGS. **7**A and **7**B are schematic views showing examples of region-based matching;

FIGS. **8**A and **8**B are schematic views showing other examples of region-based matching;

FIG. **9** is a schematic view showing a displacement amount of a target position from inside the imaging region;

FIG. **10** is a flowchart relating to a method for setting a renewed target position from the image inside the imaging region;

FIG. **11** is an explanatory diagram concerning a method for selecting candidate positions from inside the imaging region;

FIG. **12** is a flow chart relating to a method for measuring the length of the measurement object; and

FIG. **13** is an outline front view representing a positional relationship of a target position set on a front surface of the measurement object.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As shown in FIG. **1**, the position measurement apparatus **10** is equipped with a sensor head **12** that captures an optical image irradiated from a surface of a measurement object, an image processor **14** for implementing desired image processing with respect to a two-dimensional image signal (hereinafter referred to simply as an image signal) acquired by the sensor head **12**, and cables **16** enabling electrical communications between the sensor head **12** and the image processor **14**, and which are capable of supplying power to the sensor head **12** from the image processor **14**.

Further, the image processor **14** is connected electrically to an upper level controller **18**, which is an external apparatus. The upper level controller **18** is constituted, for example, from a PLC (programmable logic controller), which sends various types of commands to the image processor **14**, and controls driving of a conveyor **20** disposed underneath the sensor head **12**.

The conveyor **20** comprises a cylindrical drive roller **21**, a driven roller **22**, and a band-shaped belt **24**, which is trained between the drive roller **21** and the driven roller **22**. The drive roller **21** is rotated in the direction of the solid line arrow (see FIG. **1**) through operation of the upper level controller **18**, such that simultaneously with movement of the belt **24** in the direction of the outline arrow (see FIG. **1**), a workpiece (measurement object) **26** mounted on the conveyor **20** is transported in the direction of the outline arrow.

The sensor head **12** of the position measurement apparatus **10** is fixedly disposed above the conveyor **20** with an imaging surface **28** thereof being directed toward the side of the belt **24**. At this time, an imaging region **30** of the sensor head **12** is set on a surface **32** of the workpiece **26**, which is mounted on the conveyor **20**.

Next, with reference to FIG. **2**, which shows a functional control block of the position measurement apparatus **10** according to the present embodiment, explanations shall be given concerning the sensor head **12** and the image processor **14**.

The sensor head **12** comprises an illuminating unit **34**, an image capturing section **36**, a communications unit **38**, and a sensor head controller **40**.

The illuminating unit **34** is constituted by a lamp that irradiates illuminating light **46** toward the imaging region **30** disposed on the surface **32** of the workpiece **26**. The lamp can be turned on and off by a non-illustrated illumination switch.

The image capturing section **36** includes an image capturing element (image sensor) **50** for converting reflected light **48** (a reflected optical image of the workpiece **26**) reflected by the surface **32** of the workpiece **26** and which is incident on the imaging surface **28** into an image capturing signal, and a signal processor **52** for amplifying the image capturing signal and outputting the same to the sensor head controller **40** in synchronism with timing control signals from the sensor head controller **40**. The image capturing element **50**, for example, may be constituted by a photodiode array, a CCD, a CMOS image capturing element, or the like.

A non-illustrated imaging optical system is disposed at an intervening position between the workpiece **26** and the image capturing element **50**, which is capable of changing the dimension, i.e., the imaging magnification ratio, of the imaging region **30** that is irradiated onto the surface **32** of the workpiece **26**. Further, by means of the imaging optical system, suitable optical path adjustments are performed so that image distortions do not occur in the image capturing signals acquired by the image capturing element **50**.

In accordance with a command from the sensor head controller **40**, the communications unit **38** carries out communications with the image processor **14**. In this case, through use of LVDS (low voltage differential signaling), energy consumption can be suppressed, and high-speed signal transmissions that are robust or resistant to noise can be carried out.

The image processor **14** is equipped with a communications unit **54**, a storage unit **56**, an image processing unit **58**, an operating unit **60**, a display **62**, an external communications unit **64**, an external communications unit **66**, and a controller **68**.

The communications unit **54**, following a command from the controller **68**, carries out mutual communications with the sensor head **12**. The storage unit **56** comprises an image memory **70** for storing image signals obtained from the sensor head **12**, a RAM **71** for temporarily storing various parameters used for image processing and the like, and an EEPROM **72** for storing intrinsic data including an identification number of the sensor head **12**, sensor sensitivity characteristics, etc.

The image processing unit **58** comprises an extracting unit **74**, a determining unit **75**, a detecting unit **76**, a computational unit **77**, and a measurement unit **78**, which are constituted by software and hardware.

The operating unit **60** is constituted by switches and operating buttons, etc., not shown, which are used for making various different settings. The display **62** is constituted, for example, from an LCD panel, on which various numerical values or the like relating to measurement conditions and/or measurement results are displayed.

The two external communications units **64**, **66** are provided to enable connections to external apparatus. For example, the external communications units **64**, **66** can be connected to the upper level controller **18** to transmit/receive commands and various data with it, or connected to external personal computers (PC), not shown, or connected to another unillustrated image processor **14** for data communication. Such communications are not solely restricted to general communications standards such as USB 2.0, IEEE1394, RS-232C and the like, but can also utilize other communications standards unique to the image processor **14**.

In FIG. **1** and FIG. **2**, the image processor **14** is connected to the upper level controller **18** via the external communications unit **66**.

The controller **68** carries out general comprehensive control of the entire image processor **14**, including control functions for controlling the communications unit **54**, the storage unit **56**, the image processing unit **58**, the operating unit **60**, the display **62**, and the external communications units **64**, **66**.

In the position measurement apparatus **10**, the sensor head **12**, and the image processor **14** shown in FIG. **1** are provided as separate individual units. Alternatively, the sensor head **12** and the image processor **14** may be constructed integrally. In that case, a condensed structure may be adopted for dispensing with the communications unit **38** and the communications unit **54**.

The position measurement apparatus **10** according to the present embodiment basically is constructed as described above. Next, operations of the position measurement apparatus **10** shall be explained with reference to the flowchart shown in FIG. **4**.

At first, after the workpiece **26**, which serves as a measurement object, has been mounted on the conveyor **20**, position and attitude adjustments of the sensor head **12** (see FIG. **1**) of the position measurement apparatus **10** are carried out. As shown in FIG. **2**, a user performs an ON/OFF operation of a non-illustrated illumination switch of the operating unit **60**, so that a command for turning on and off the illuminating unit **34** is made with respect to the sensor head controller **40** through the operating unit **60**, the controller **68**, the communications unit **54**, the cables **16**, and the communications unit **38**. Desired operations of the illuminating unit **34** are performed by on and off controls of the sensor head controller **40**. Since illuminating light **46** from the illuminating unit **34** is irradiated toward the surface **32** of the workpiece **26**, the position of the imaging region **30** can be confirmed while the user performs adjustments on the position and attitude of the sensor head **12**.

As shown in FIG. **1** and FIGS. **3**A through **3**C, a circular groove **82**, a triangular groove **84**, a square groove **86**, and another circular groove **88** are arranged in order from the right, or more specifically, from a downstream side of the transport direction according to the present embodiment, on the surface **32** of the workpiece **26**. In FIG. **3**A, a condition (initial condition) before the position measurement apparatus **10** performs measurement is shown. The circular groove **82** resides in a substantially center portion of the imaging region **30**, whereas a part of the triangular groove **84** resides at the left side edge of the imaging region **30**.

If patterns of contrasting density exist as images on the surface **32** of the workpiece **26**, then the features of the present invention can still be applied even though specialized grooves such as those having three-dimensional shapes are not present.

As shown in FIG. **1**, when the drive roller **21** is rotated in the direction of the arrow, the belt **24** is moved slidably in the direction of the outline arrow, and the workpiece **26**, which is mounted on the belt **24** of the conveyor **20**, also is transported in the direction of the outline arrow. By such a transporting operation of the workpiece **26**, the positional relationship between the workpiece **26** and the imaging region **30** changes successively over time from the initial state shown in FIG. **3**A to the states shown in FIG. **3**B and FIG. **3**C.

When carried out in this manner, while the surface **32** of the workpiece **26**, which is larger than the imaging region **30**, is moved relatively due to the transporting operation of the conveyor **20**, images can be captured of each of the grooves (the circular groove **82**, etc.) on the surface **32** of the workpiece **26** by the sensor head **12**.

Below, with reference to the flowchart shown in FIG. **4**, detailed explanations shall be made concerning a measurement method for measuring a length of the workpiece **26** using the position measurement apparatus **10** according to the present embodiment.

[Step S**1**]

When a user presses a measurement initiating button (not shown) of the operating unit **60** shown in FIG. **2**, a request to initiate image capturing is notified to the sensor head controller **40** via the operating unit **60**, the controller **68**, the communications unit **54**, the cables **16**, and the communications unit **38**. Thereafter, the sensor head controller **40** emits an image capturing command to the image capturing section **36**.

Initially, an image signal at a time t=0 is acquired (step S**1**). More specifically, an image signal is acquired showing an image I(**0**) inside the imaging region **30** at the time t=0.

In this case, reflected light **48** for forming a reflected optical image of the workpiece **26** is directed toward the imaging surface **28**, and after appropriate optical path adjustments have been made in the non-illustrated imaging optical system, electro-optical conversion is carried out by the image capturing element **50** within the range of the imaging region **30**, and an image signal is issued. The image signal is synchronized with timing control signals from the sensor head controller **40** and amplified, and the image signal is supplied to the sensor head controller **40**. The image signal thereafter is supplied to the communications unit **38**, and is stored in the image memory **70** through the cables **16**, the communications unit **54**, and the controller **68**.

In this manner, as shown in FIG. **5**A, an image I(**0**) inside the imaging region **30** is acquired (see also FIG. **3**A). As shown in FIG. **6**A, in the image signal representing the image I(**0**) inside the imaging region **30**, the gradation number of each of the pixels (64 vertical, 64 horizontal) is made up of 256 gradations (8-bit). For convenience, the pixel number in the vertical direction shall be labeled from −31 to 32, and the pixel number in the horizontal direction also shall be labeled from −31 to 32, respectively.

[Step S**2**]

Next, a target position P_0 from the image I(**0**) inside the imaging region **30** is set (step S**2**).

Among the image signals stored in the image memory **70**, an image signal (see FIG. **5**A) is read out, which represents the image I(**0**) inside the imaging region **30**, and the extracting unit **74** extracts the pattern on the surface of the workpiece **26**

from inside the image I(**0**). According to the present embodiment, for specifying the position of the pattern extracted by the extracting unit **74**, as a representative position, the center position of the circular groove **82** is determined and set as the target position P_0.

For example, using a two-dimensional (x-y) coordinate system as shown in FIG. **6**B, corresponding positions for each of the pixels inside the imaging region **30** are defined. The scale of the coordinate system is defined such that one graduation, in each of the x-axis and y-axis directions, corresponds in size to the pixel size (i.e., having dimensions equal to those of one pixel).

When defined in this manner, the two dimensional coordinates corresponding to the pixels **90**, **92**, **94**, **96** and **98** shown in FIG. **6**A are (0, 0), (32, 32), (−31, 32), (−31, −31) and (32, −31), respectively.

As shown in FIG. **5**A, because at time t=0, the circular groove **82** resides substantially at the center position of the image I(**0**), the circular groove **82** is extracted as a pattern. At this time, as noted above, the target position P_0 is set at an origin (0, 0), which corresponds to the center position of the circular groove **82**. Along therewith, the coordinates of the target position P_0 (0, 0) are stored in the storage unit **56** (e.g., RAM **71**).

[Step S**3**]

Next, an image signal I(**1**) at a time t=1 is acquired (step S**3**). More specifically, an image signal is acquired showing an image I(**1**) inside the imaging region **30** at the time t=1.

At time t=1, the sensor head controller **40** emits an image capturing command with respect to the image capturing section **36**, and an image signal that represents the newly captured image I(**1**) is stored in the image memory **70**. These operations are essentially the same as those already described above, and therefore detailed explanations thereof have been omitted.

In this manner, the image I(**1**) inside the imaging region **30** is acquired, as shown in FIG. **5**B. Although it is possible for the image capturing period Δt to be set at any optional value, in order to facilitate explanations, in the present specification, the image capturing period Δt is assumed to be 1. Further, it goes without saying that the present invention is applicable even in cases where the image capturing period Δt is not a constant value, or stated otherwise, when the time interval between successively captured images is irregular.

[Step S**4**]

Next, the target position P_0 from the image I(**1**) inside the imaging region **30** is sought (step S**4**).

Among the image signals stored in the image memory **70**, an image signal (see FIG. **5**B) is read out, which corresponds to the image I(**1**), and the detecting unit **76** detects the target pattern P_0 from inside the image I(**1**).

As a method for identifying a predetermined common position (or a common area) from among the two images I(**1**) and I(**0**), region-based matching, which is a well known technique, can be adopted.

FIGS. **7**A and **7**B are schematic views showing examples of region-based matching.

As shown in FIG. **7**A, a region of a predetermined size (e.g., a 16×16 pixel region), in which the target position P_0 is at the center of the image I(**0**), is extracted and stored beforehand as a template **100** in the storage unit **56** (e.g., RAM **71**). On the other hand, a concerned region **102**, in which an optional position (e.g., in FIG. **7**A, a center right side of the imaging region **30**) is taken as the center, is cut out from the image I(**1**) inside the imaging region **30**. The pixel size (vertical and horizontal pixel number) of the concerned region **102** matches that of the template **100**.

By causing an NCC (Normalized Cross Correlation) operator **104** to act on the template **100** and the concerned region **102**, an NCC value is calculated, which serves as an index to indicate the degree of similarity between the two compared images. Since this technique is well known in the field of image processing, detailed explanations of this feature of the present invention shall be omitted.

In FIG. **7**A, since the concerned region **102** closely resembles the template **100**, a large NCC value is shown. On the other hand, in FIG. **7**B, a concerned region **106**, in which an optional position (e.g., in FIG. **7**B, a center left end of the imaging region **30**) of the image I(**1**) inside the imaging region **30** is taken as the center, is cut out, and since the concerned region **106** does not closely resemble the template **100**, a small NCC value is shown.

In this manner, a center position of the concerned region **102**, for which the NCC value from among the image I(**1**) inside the imaging region **30** is maximum, can be presumed to be the target position P_0 in the image I(**1**).

FIGS. **8**A and **8**B are schematic views showing other examples of region-based matching.

In FIGS. **8**A and **8**B, by causing a SAD (Sum of Absolute Difference) operator **108** to act on the template **100** and the concerned regions **102**, **106**, which have been cut out as noted above, a SAD value is calculated, which serves as an index to indicate the degree of difference between the two compared images. Since this technique is well known in the field of image processing, detailed explanations of this feature of the present invention shall be omitted.

In FIG. **8**A, since the concerned region **102** closely resembles the template **100**, a small SAD value is shown. On the other hand, in FIG. **8**B, a concerned region **106**, in which an optional position (e.g., in FIG. **8**B, a center left end of the imaging region **30**) of the image I(**1**) inside the imaging region **30** is taken as the center, is cut out, and since the concerned region **106** does not closely resemble the template **100**, a large SAD value is shown.

In this manner, a center position of the concerned region **102**, for which the SAD value from among the image I(**1**) inside the imaging region **30** is minimum, can be presumed to be the target position P_0 within the image I(**1**).

FIG. **9** is a schematic view showing a displacement amount of a target position P_0 from inside the imaging region **30**. When the search result for the position P_0 in step S**4** is calculated, while the digits to the right of the decimal point are discarded, such that $P_0(t=0)=(0, 0)$ and $P_0(t=1)=(14, 0)$, the displacement amount of the target position P_0 becomes the vector value $\Delta P_0=(14, 0)$.

Because the image signal representing the image I(t) consists of discrete data, the coordinates of the target position P_0 can be expressed only by an integral multiple (in other words, an integer value) of the pixels. However, by utilizing sub-pixel estimation, coordinate values that exceed the pixel resolution can be expressed.

In this case, "sub-pixel estimation" implies a position estimating method in which rational numbers are introduced virtually when coordinates are expressed by discrete data. As a result, spatial resolution can be improved artificially, and quantization errors can be prevented from occurring.

Next, a detailed example concerning sub-pixel estimation shall be described. First, an NCC (or SAD) value is determined about a central position of each pixel of the image signal, and then a 3-pixel-by-3-pixel region in the vicinity of the maximum (or minimum) value thereof is extracted. A tendency (three pairs of data) of the NCC (or SAD) with respect to the x-axis is interpolated at a two-dimensional curve, and a position (rational number value of the pixel)

corresponding to the axis of the two-dimensional curve is calculated and determined as an x-axis coordinate of the target position P_0. Similarly, a tendency (three pairs of data) of the NCC (or SAD) with respect to the y-axis is interpolated at the two-dimensional curve, and a position (rational number value of the pixel) corresponding to the axis of the two-dimensional curve is calculated and determined as a y-axis coordinate of the target position P_0. In this manner, the x and y coordinates of the target position P_0 can be determined.

In the event that sub-pixel estimation is used, the search results of the target positions P_0 shown in FIG. **9** are $P_0(t=0)=(0, 0)$ and $P_0(t=1)=(14.5, 0)$, and the displacement amount of the target position P_0, with higher precision, becomes the vector value $\Delta P_O=(14.5, 0)$.

Further, sub-pixel estimation in the present embodiment is not limited to the aforementioned method, and various other types of methods could be adopted.

[Step S**5**]

Next, a judgment is performed to determine whether or not the position corresponding to the target position P_0 resides in the image I(**1**) inside the imaging region **30** (step S**5**). This judgment is carried out by the determining unit **75** (see FIG. **2**) based on the search result of the target position P_0 in step S**4**.

For example, in the case that a portion is lacking from the pattern (circular groove **82**) pertaining to the target position P_0 in the image I(**1**) inside the imaging region **30**, when a search calculation by means of the aforementioned region-based matching is carried out, irrespective of whether the target position P_0 currently resides inside the imaging region **30**, there is the possibility for the search to fail.

In such a case, a concern can be noted that the pattern (circular groove **82**) extracted by the extracting unit **74** may miss the imaging region **30** when the next image is taken, which can be included in the judgment that the pattern does not reside in the image I(**1**) inside the imaging region **30** at the present time.

[Step S**6**]

In the case it is judged that the position corresponding to the target position P_0 resides in the image I(**1**) inside the imaging region **30**, the vector ΔP_0, which indicates the displacement amount of the target position P_0 from the image I(**0**) to the image I(**1**), is calculated (step S**6**), and the value thereof is stored in the storage unit **56** (e.g., RAM **71**). This calculation is carried out by the computational unit **77** shown in FIG. **2**.

[Step S**7**]

Next, the predetermined length on the surface **32** of the workpiece **26**, which makes up the measurement object, is measured (step S**7**). Details of the method by which this step is performed will be explained later.

[Steps S**8** to S**9**]

Next, an image capture ending judgment (step S**8**) is performed. In the case that image capturing is continued using the sensor head **12** without an image capture ending command being issued by means of a hardware or software interrupt, a predetermined time period is waited for until it becomes possible to acquire an image signal representing the image I(**2**) at the next time (t=2) (step S**9**).

From this point forward, image capturing is continued and steps S**3** to S**9** are repeated, so long as the position corresponding to the target position P_0 resides within the image I(t) inside the imaging region **30**.

[Step S**10**]

Thereafter, as shown in FIG. **3**B, at a predetermined time t, in the case it is determined for the first time that the position corresponding to the target position P_0 does not reside in the Image I(t) inside the imaging region **30**, a new target position P_1, which differs from the target position P_0, is set from the Image I(t) inside the imaging region **30** (step S**10**). As shown in FIG. **2**, from among the image signals stored in the image memory **70**, an image signal corresponding to the image I(**0**) is read out, and a new pattern on the surface **32** of the workpiece **26** is extracted from inside the image I(**0**) by the extracting unit **74**. Similar to step S**1**, a target position P_1 is determined and set as a representative position of the new pattern extracted by the extracting unit **74**, and along therewith, the coordinates of the new target position P_1 are stored in the storage unit **56** (e.g., RAM **71**).

Next, detailed explanations shall be given with reference to the flowchart of FIG. **10** concerning a method for setting the new target position P_1, which differs from the target position P_0, from the image I(t) inside the imaging region **30**.

First, extraction of candidate positions is carried out based on the pixel value distribution (step S**101**).

In the case that the area in the neighborhood of the newly set target position P_1 possesses an average pixel value overall, searching for the target position P_1 (step S**4** shown in FIG. **4**) in the image I(t) inside the imaging region **30** would be extremely difficult. Consequently, a position where the possibility for searching is promising, i.e., in which the variance in pixel values of neighboring pixels is comparatively large, is extracted as a candidate position $\{Q_j\}$ for the target position P_1.

Herein, a case is considered in which a plurality of individual (M) candidate positions exists, and such a group of candidate positions is noted by $\{Q_i\}(j=1, 2, \ldots, M)$.

As shown in FIG. **11**, taking the center pixel (0, 0) of the imaging region as a starting point, image characteristic values concerning each of pixels oriented in the directions of four arrows (S_E, S_N, S_W, S_S) are calculated successively, and the pixel for which the pixel characteristic value thereof exceeds for the first time a predetermined value is selected as a candidate position. In this case, the pixel characteristic value is defined as an evaluation value, which becomes larger accompanying an increase in the pixel value variance of neighboring pixels. For example, a standard deviation inside the concerned region (defined, as with the concerned region **102** and the like shown in FIG. **7**), or a sum total of the difference in signal values between the pixel values and the average value thereof within the concerned region, or the like, can be used as the pixel characteristic value.

Since the triangular groove **84** resides in the direction of the S_E arrow, whereas the square groove **86** resides in the direction of the S_W arrow, a barycentric (center of gravity) position therebetween is selected as the candidate position. On the other hand, with respect to the direction of the arrow S_N and the arrow S_S from the center pixel (0, 0), because the pixel values up to the vicinity of the border of the imaging region **30**, for which pixel characteristic values concerning each of the pixels are calculated, are uniform, calculations are completed, concluding that the candidate position $\{Q_j\}$ does not reside therein.

If the above-described method is adopted, compared to the case of calculating pixel characteristic values with respect to all of the pixels inside the imaging region, the arithmetic operational amount required for processing can be dramatically reduced. Carried out in this manner, a maximum of four (two as shown in FIG. **11**) candidate positions $\{Q_j\}$ are extracted.

Next, the positional relationship between the previous target position P_0 and the candidate positions $\{Q_j\}$ is investigated (step S**102**).

It is essential that the previous position P_0 and the target position P_1 set at the current time exist together within at least one image I(t) inside the imaging region **30**. Otherwise, the mutual positional relationship between the target position P_0 and the target position P_1 cannot be identified. Therefore, with respect to all of the candidate positions $\{Q_j\}$ extracted in step **S101**, it is first investigated whether or not the target position P_0 and the candidate position $\{Q_j\}$ CO both exist together within at least one image I(t) inside the imaging region **30**.

Making use of the fact that the target position P_0 definitely exists within the image I(t−**1**) inside the imaging region **30**, a method can be adopted to determine whether or not the candidate position $\{Q_j\}$ also exists within the image I(t−**1**) inside the imaging region **30**. In this case, the region-based matching technique, which was described above, can be used.

Lastly, one position from among the candidate positions $\{Q_j\}$ is selected, and the new target position P_1 is set at the aforementioned one position (step **S103**). For example, in the case that one individual candidate position $\{Q_j\}$ resides in the image I(t−**1**) inside the imaging region **30**, the target position P_1 is set at the candidate position. In the case that a plurality of individual candidate positions $\{Q_j\}$ reside in the image I(t−**1**) inside the imaging region **30**, the target position P_1 is set at one candidate position for which the image characteristic value thereof is maximum from among the plurality of candidate positions $\{Q_j\}$.

In this manner, a new target position P_1, which differs from the target position P_0, can be set from the image I(t) inside the imaging region **30**.

Step S**11**

Next, a vector P_0P_1, which is a tracking displacement amount of the target position P_0, is calculated (step S**11**). This calculation is performed in the computational unit **77** shown in FIG. **2**.

According to the present embodiment, because the target position P_1 is set such that the target positions P_0 and P_1 both reside in the image I(t−**1**) inside the imaging region **30**, the vector P_0P_1 can easily be determined. In this manner, by performing steps S**10** and S**11**, the new target position P_1 (general equation: P_{i+1}) is set with respect to the current target position P_0 (general equation: P_i).

Next, a judgment to terminate image capturing is performed (step S**8**). At the current time, in the case that image capturing is to continue without a command to terminate the same, a predetermined time is maintained until a next time (t+**1**) during which acquisition of the image I(t+**1**) from inside the imaging region **30** is enabled (step S**9**).

[Detailed Description of Step S**7**]

As discussed above, while image capturing is being conducted, that is in real time, a predetermined length is measured on the surface **32** of the workpiece **26**, which serves as the measurement object (step S**7**). Below, with reference to the flowchart shown in FIG. **12**, the measurement method shall be described in greater detail.

Using the position measuring method according to the present embodiment, (N+**1**) individual target positions (N is a positive integer), or more specifically, positions P_0 to P_N are set on the surface **32** of the workpiece **26** (see FIG. **13**). Data of the tracking displacement amount vector $\{P_iP_{i+1}\}$ stored in the RAM **71** shown in FIG. **2** is read out, and based on such data, length measurement is performed by the measurement unit **78**.

First, a first point X_1 defining a length measurement starting point and a second point defining a length measurement end point are designated (step S**71**). As one example of designating such points, referring to the image displayed on the display **62** shown in FIG. **2**, the user, by a setting means such as a GUI or the like, can set the first point X_1 and the second point X_2. Further, a marker for enabling discrimination of the starting point and end point on the surface **32** of the workpiece **26** may be implemented. The user, prior to initiation of length measurement, normally sets beforehand the first point X_1 as the starting point of the length measurement.

Next, a target position $P_m(0\leq m\leq N)$ is determined in the vicinity of the first point X_1 (step S**72**). Herein, in at least one image I(t) inside the imaging region **30**, it is necessary for the first point X_1 and the target position P_m both to exist. Assuming there is a target position P_m that fulfills this condition, any position may be selected.

Next, a vector X_1P_m defining the relative position between the first point X_1 and the target position P_m is calculated (step S**73**). Since the first point X_1 and the target position P_m both reside within the region represented by the image $I(t_1)$ inside the imaging region **30** at the predetermined time t_1, the vector X_1P_m can easily be determined.

Next, a target position $P_n(0\leq m<n\leq N)$ in the vicinity of the second point X_2 is determined (step S**74**). Herein, in at least one image I(t) inside the imaging region **30**, it is necessary for the second point X_2 and the target position P_n, both to exist. Assuming there is a target position P_n, that fulfills this condition, any position may be selected.

Next, a vector X_2P_n defining the relative position between the second point X_2 and the target position P_n is calculated (step S**75**). Since the second point X_2 and the target position P_n both reside within the region represented by the image $I(t_2)$ inside the imaging region **30** at the predetermined time t_2, the vector X_2P_n can easily be determined.

Lastly, a displacement vector between the first point X_1 and the second point X_2 is calculated (step S**76**). The displacement vector X_1X_2 is determined by the following equation (1).

$$\begin{aligned}\overrightarrow{X_1X_2} &= \overrightarrow{X_1P_m} + \overrightarrow{P_mP_{m+1}} + \ldots + \overrightarrow{P_{n-1}P_n} + \overrightarrow{P_nX_2} \\ &= \overrightarrow{X_1P_m} + \sum_{i=m}^{n-1} \overrightarrow{P_iP_{i+1}} + \overrightarrow{P_nX_2} \\ &(0 \leqq m < n \leqq N)\end{aligned} \tag{1}$$

In this manner, the target position $\{P_i\}$, which is a representative position of the pattern extracted by the extracting unit **74** (FIG. **2**), functions as a tracking point. As a result, an optional position inside the image in which at least one target position exists can be expressed by the above equation (1).

Lastly, by multiplying the image size (the dimension of 1 pixel) with respect to the x-axis displacement amount and the y-axis displacement amount that define units of the pixel number, the length in actual dimensions can be determined. Further, the pixel size can be calculated based on the image capturing magnification ratio (which is set in the non-illustrated imaging optical system), and the resolution of the image capturing element **50**, which is known.

Moreover, prior to measuring the length, by taking an image of a high precision reference target object (the size of which is already known), measuring the pixel number, and dividing the pixel number from the known size, the pixel size can be determined.

Further, if the position of the first point X_1, which is the measurement starting position, is set beforehand, the aforementioned position measuring method can still be realized, even with a configuration in which only the image signal representing the image I(t) necessary to specify the target

position $\{P_i\}$ may be stored in the image memory **70** of the storage unit **56**, and an image signal representing the other image I(t) thereof is not stored (i.e., the other image I(t) is destroyed after predetermined image processing thereon is performed). In this case, a favorable condition exists in that the memory capacity of the storage unit **56** can be reduced, as well as reducing the number of times that the memory is accessed.

The position measurement apparatus and positioning measuring method according to the present invention are not limited to the embodiments described above, and various alternative or additional features and structures may be adopted without deviating from the essence and scope of the invention.

For example, although in the present embodiment a structure is adopted in which illuminating light **46** is reflected from the surface **32** of the workpiece **26** and a reflected optical image therefrom is captured by the image capturing element **50**, natural light may also be used, or an optical image emitted from the measurement object itself can be captured by the image capturing element **50**.

Further, the image capturing element **50** can be constructed from a monochrome sensor (i.e., a sensor element having a single light reception wavelength characteristic) or a color sensor (i.e., a sensor element having a multiple-type light reception wavelength characteristic). In this case, the image processor **14** can perform communications and image processing appropriate to the data type of the acquired image signals.

Furthermore, although in the present embodiment a case has been shown in which the position and attitude of the sensor head **12** are fixed, and the workpiece **26** mounted on the conveyor **20** is moved by being transported on the conveyor **20**, the means for causing relative movement of the sensor head **12** above the surface **32** of the workpiece **26** is not limited to this case. For example, image capturing may also be carried out by moving the sensor head **12** in parallel with respect to the surface **32** of the workpiece **26** while the workpiece **26** remains fixed in position. Further, the measurement object itself may include a driving mechanism, whereby an image is captured of the moving measurement object.

Further, assuming a configuration in which known conventional image recognition processing techniques are incorporated in the image processing unit **58**, not only two dimensional length measurements, but shape discrimination and color discrimination processes can also be performed.

Further, in the position measurement apparatus and position measuring method according to the present invention, not only two dimensional coordinates (X, Y), but also three dimensional coordinates (X, Y, Z), can be applied. In this case, displacements in the z-axis direction can be realized by detecting an enlargement/reduction ratio of the patterns.

Furthermore, if position measurements are made at two optional points, the length, three dimensional displacement, and angle (angular displacement about a third position) thereof can be uniquely determined. Accordingly, the position measurement apparatus and position measuring method according to the present invention not only serves as a length measurement sensor and a displacement sensor, but can also be applied as an angle sensor, a velocity sensor, or the like.

What is claimed is:

1. A position measurement apparatus in which an image capturing element having an imaging region of a dimension smaller than that of a measurement object is moved relatively over a surface of the measurement object while an image on the surface of the measurement object is captured to obtain an image inside the imaging region, and a position on the surface of the measurement object is measured using the obtained image inside the imaging region, comprising:

an extracting unit for extracting a pattern on the surface of the measurement object from the image inside the imaging region at a predetermined point in time;

a detector for detecting a displacement amount of the pattern extracted by the extracting unit occurring in the image inside the imaging region at a point in time after the predetermined point in time;

a measurement unit for measuring the position on the surface of the measurement object based on the dimension and the displacement amount detected by the detector; and

a storage unit for storing position information concerning the pattern extracted by the extracting unit, wherein

the extracting unit extracts a renewed pattern on the surface of the measurement object, which differs from the pattern, from the image inside the imaging region in which the pattern exists,

the storage unit stores a tracking displacement amount, which is a vector from a position of the pattern to a position of the renewed pattern, each time the renewed pattern is extracted,

the measurement unit further measures the position on the surface of the measurement object based on each of a plurality of tracking displacement amounts stored in the storage unit, and

the measurement unit measures the position on the surface of the measurement object based on the displacement amount, the dimension, and the position information stored by the storage unit.

2. The position measurement apparatus according to claim **1**, further comprising a determining unit for carrying out a determination as to whether or not the pattern extracted by the extracting unit exists in the image inside the imaging region at present time,

wherein, when it is determined by the determining unit that the pattern does not exist in the image inside the imaging region at the present time, the extracting unit extracts the renewed pattern from the image inside the imaging region at the present time.

3. The position measurement apparatus according to claim **1**, wherein:

the storage unit stores a template of the pattern; and

the detector calculates the displacement amount of the pattern based on region-based matching using the template stored by the storage unit.

4. The position measurement apparatus according to claim **1**, wherein the detector detects the displacement amount by utilizing sub-pixel estimation.

5. The position measurement apparatus according to claim **1**, wherein the extracting unit extracts, as the renewed pattern, a pattern that is different from the pattern and has neighboring pixels having a pixel variance exceeding a predetermined value.

6. The position measurement apparatus according to claim **1**, further comprising a determining unit for determining whether the pattern extracted by the extracting unit exists in the image inside the imaging region at present,

wherein the extracting unit extracts the renewed pattern from an image that comes right before the image used by the determining unit when the determining unit determines that the pattern extracted by the extracting unit does not exist in the image.

7. The position measurement apparatus according to claim **1**, wherein a length on the surface of the measurement object includes a position other than the position information con-

cerning the pattern on the surface of the measurement object extracted by the extracting unit.

8. The position measurement apparatus according to claim **7**, wherein the length is a total length of the measurement object.

9. The position measurement apparatus according to claim **7**, wherein the length on the surface of the measurement object includes a position specified by a user.

10. The position measurement apparatus according to claim **7**, wherein the length is defined by at least two points specified by a user.

11. A position measuring method in which an image capturing element having an imaging region of a dimension smaller than that of a measurement object is moved relatively over a surface of the measurement object while an image on the surface of the measurement object is captured to obtain an image inside the imaging region, and a position on the surface of the measurement object is measured using the obtained image inside the imaging region, the method comprising the steps of:

extracting a pattern on the surface of the measurement object from the image inside the imaging region at a predetermined point in time;

detecting a displacement amount of the pattern extracted by an extracting unit occurring in the image inside the imaging region at a point in time after the predetermined point in time;

measuring the position on the surface of the measurement object based on the dimension and the displacement amount detected by a detector;

storing by a storage unit position information concerning the pattern extracted by the extracting unit;

extracting a renewed pattern on the surface of the measurement object, which differs from the pattern, from the image inside the imaging region in which the pattern exists;

storing by the storage unit a tracking displacement amount, which is a vector from a position of the pattern to a position of the renewed pattern, each time the renewed pattern is extracted,

wherein measuring the position on the surface of the measurement object includes measuring the position on the surface of the measurement object based on each of a plurality of tracking displacements amounts stored in the storage unit, and measuring the position on the surface of the measurement object based on the displacement amount, the dimension, and the position information stored by the storage unit.

12. The position measuring method according to claim **11**, wherein, after the detecting step is performed, further comprising a determining step for determining by a determining unit whether or not the pattern extracted by the extracting unit exists in the image inside the imaging region at present time.

13. The position measuring method according to claim **11**, wherein a length on the surface of the measurement object includes a position other than the position information concerning the pattern on the surface of the measurement object extracted.

14. The position measuring method according to claim **13**, wherein the length is a total length of the measurement object.

15. The position measuring method according to claim **13**, wherein the length on the surface of the measurement object includes a position specified by a user.

16. The position measuring method according to claim **13**, wherein the length is defined by at least two points specified by a user.

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